SECTION 1
Introduction

1.1 Overview

The King County Department of Natural Resources and Parks and its predecessor agency Municipality of Metropolitan Seattle (Metro) have a long history of water quality improvements and monitoring water quality in Puget Sound. As part of an ongoing effort to maintain and improve Puget Sound's water quality, the King County Wastewater Treatment Division oversees regional sewerage collection, treatment processes, and disposal systems that discharge wastewater to the Central Puget Sound Basin and waters flowing into the Sound. King County's Marine and Sediment Assessment Group supports a comprehensive long-term marine monitoring program that assesses water quality in the Central Puget Sound Basin on behalf of and in coordination with the Wastewater Treatment Division.

King County's marine monitoring program is part of an intergovernmental monitoring effort, the Puget Sound Assessment and Monitoring Program (PSAMP), with the County's program focusing primarily on water quality within King County's borders. Other agencies involved in PSAMP that monitor water quality and/or the environmental health of Puget Sound include the Washington State Department of Ecology (water and sediment quality), Washington Department of Fish & Wildlife (contaminants in fish tissues, herring and rockfish populations), Washington Department of Natural Resources (nearshore vegetation and habitat), Washington Department of Health (shellfish growing areas and contaminants), National Oceanic and Atmospheric Administration (contaminants in fish), and U.S. Department of Fish & Wildlife (contaminants in birds and fish). These agencies have monitoring stations throughout the Sound, including sites within King County. The main distinction between these programs and King County's monitoring program is that the County has a larger number of stations within a concentrated area which are targeted near wastewater treatment plant discharges. Although other agencies have monitoring stations within King County, the stations do not overlap with the County's stations which allows a broader area of Puget Sound marine waters to be monitored.

The objectives of the marine monitoring program are to provide an understanding of water quality within King County and to assess water quality near the County's wastewater plant outfalls to identify if discharges are affecting water quality. The County maintains a long-term dataset, consisting of over 40 years of data collected at some stations. These data provide insight into natural variations and a basis from which recent water quality conditions near outfalls and throughout the entire Puget Sound Central Basin can be assessed.

This report summarizes results of King County's outfall and ambient marine monitoring programs between 2005 and 2007. The report provides an overview of the sites monitored, matrices (e.g., water and sediment) sampled, parameters measured, and a summary of analytical results.

1.2 Wastewater Collection and Treatment

Wastewater from homes, businesses, and industries within King County and southern Snohomish County is transported through pipelines belonging to local sewer agencies to King County's system of larger pipelines (interceptors), which conveys the wastewater to the County's treatment plants. At the plants, solids are separated from liquids, which are then treated, disinfected, and discharged into Puget Sound marine waters. The separated solids are digested and the resulting rich organic material, known as biosolids, is used to enrich agricultural and forest soils and is also turned into compost.

The County's Wastewater Treatment Division provides wastewater treatment and disposal services to 17 cities, 16 local sewer and/or water districts, and the Muckelshoot Indian Tribe. The system serves about 1.4 million people in King County, southern Snohomish County, and northern Pierce County, transporting and treating over 200 million gallons of wastewater each day. To accomplish this, King County currently operates and maintains four wastewater treatment plants, four combined sewer overflow (CSO) treatment plants (Figure 1-1), 42 pump stations, and approximately 335 miles of sewer lines. The West Point Treatment Plant (TP), South TP (formerly known as the Renton and East Division Reclamation TP), Vashon Island TP, and a new, small TP in the City of Carnation provide secondary wastewater treatment. The Carnation TP provides advanced secondary treatment that discharges to the Snoqualmie River or a beneficial use wetland (the Chinook Bend Natural Area). As the Carnation TP does not discharge to marine waters, it will not be discussed further in this report.

The average wet-weather flows (based upon average wet season flows from November through April, excluding large storms) for the West Point and South TPs are 133 and 115 million gallons per day (MGD), respectively. The maximum capacity (maximum flows that can be handled by the plants for short periods with a portion of the flows receiving minimal treatment) of the West Point, South, and Vashon TPs are 440, 325, and 1.0 MGD, respectively. The Alki, Carkeek, Denny/Elliott West, and Henderson/Martin Luther King (MLK) CSO Treatment Plants store combined wastewater and stormwater flow and later pump it to the West Point TP or provide the equivalent of primary treatment and disinfection before discharging to Puget Sound or the Duwamish River (Henderson/MLK). The South TP outfall discharges at a water depth of 640 feet (ft), the West Point TP at 230 ft, the Vashon TP at 200 ft, the Alki CSO TP at 143 ft, the Carkeek CSO TP at 200 ft, the Elliott West CSO TP at 63 ft, and the Henderson/MLK CSO TP at the surface.

The West Point TP discharges the largest volume of effluent of the four secondary facilities. Between 2005-2007, the average daily discharge rate for the West Point TP was 96.7, 117.6, and 98.0 MGD, respectively. The average daily discharge rate for the South TP from 2005-2007 was 73.5, 80.0, and 79.6 MGD, respectively. The Vashon TP has the least discharge volume with average daily discharge rates of 0.1, 0.14, and 0.11 MGD from 2005-2007, respectively. Average daily wastewater discharge volumes from the two largest TPs are shown for the last five years in Figure 1-2, along with monthly total rainfall measured at SeaTac Airport. The higher discharge volumes in 2006 correspond to the high amount of rainfall, particularly for both January and November 2006. The rainfall total for January 2006 was over twice the 30-year

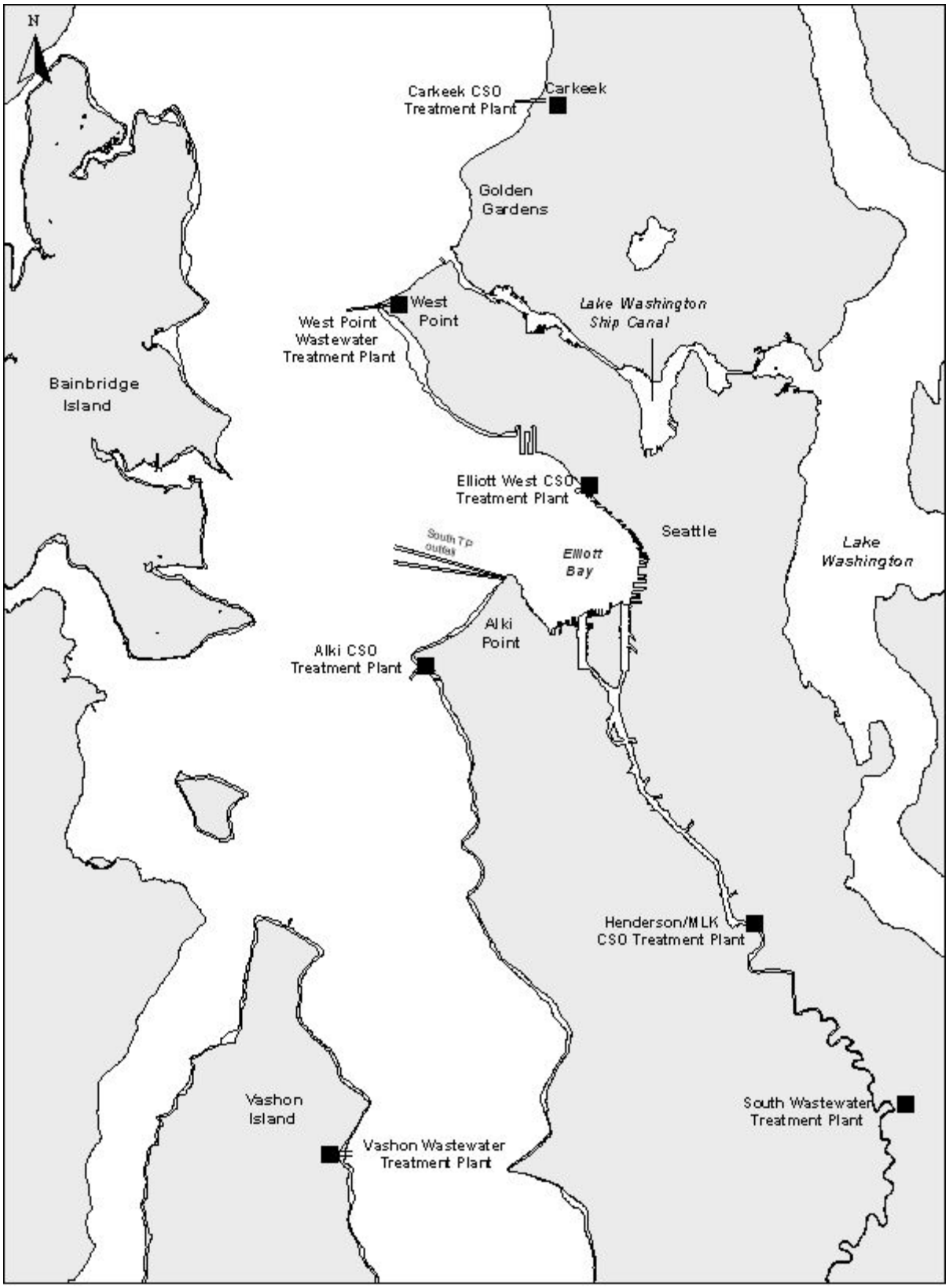

Figure 1-1. King County Wastewater & CSO Treatment Plant & Outfall Locations
(excludes Carnation TP)

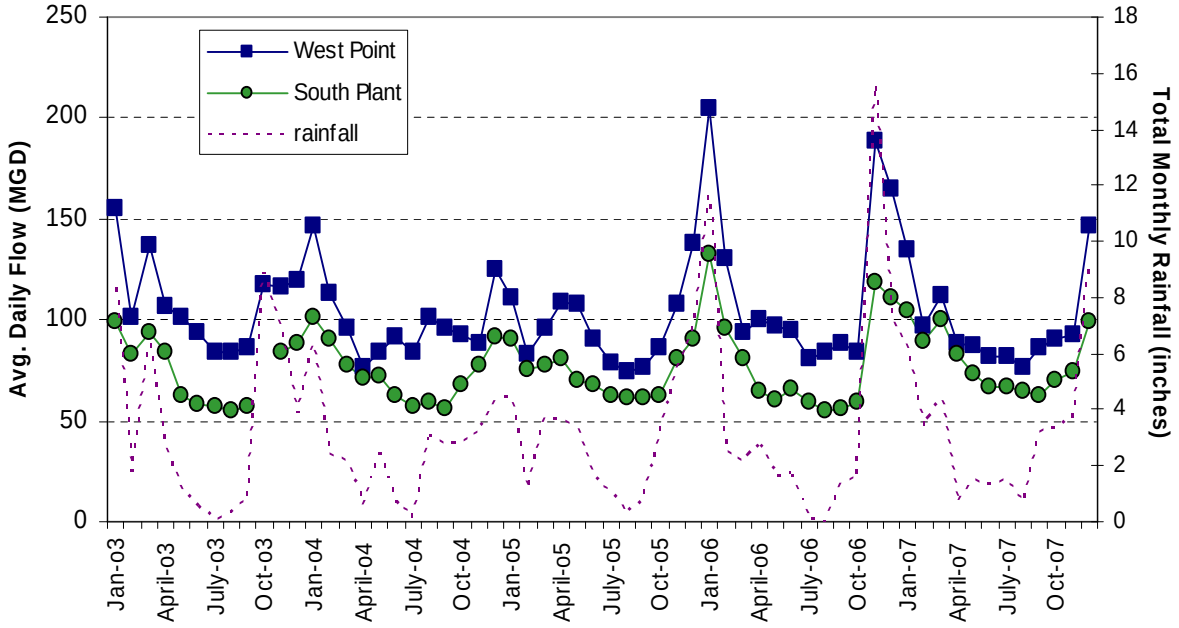

Figure 1-2. Average Daily Flow from South Plant and West Point TPs and Total Monthly Rainfall (at SeaTac) Between 2003 and 2007

average for that month and the total in November 2006 was almost 2.5 times the 30-year average. The rainfall total in 2005 was slightly under the 30-year annual average while 2007 was slightly over. The average discharge volumes shown in Figure 1-2 reflect annual rainfall patterns as effluent discharges peak during times of high rainfall, with January and February typically having the highest average discharge rates (see Section 3.1 for detailed rainfall patterns). Average daily wastewater discharge volumes from the Vashon TP are shown for the last five years in Figure 1-3 along with total rainfall amounts measured at the treatment plant. Vashon Island receives more rainfall than in other parts of King County. Therefore, when comparing discharge volumes with rainfall, using rainfall measured on Vashon Island is more applicable than SeaTac totals.

A summary of the discharge events and volumes for the Alki, Carkeek, and Elliott West CSO treatment facilities may be found on the Wastewater Treatment Division's CSO website at http://www.kingcounty.gov/environment/wastewater/CSO/Library/AnnualReports.aspx.

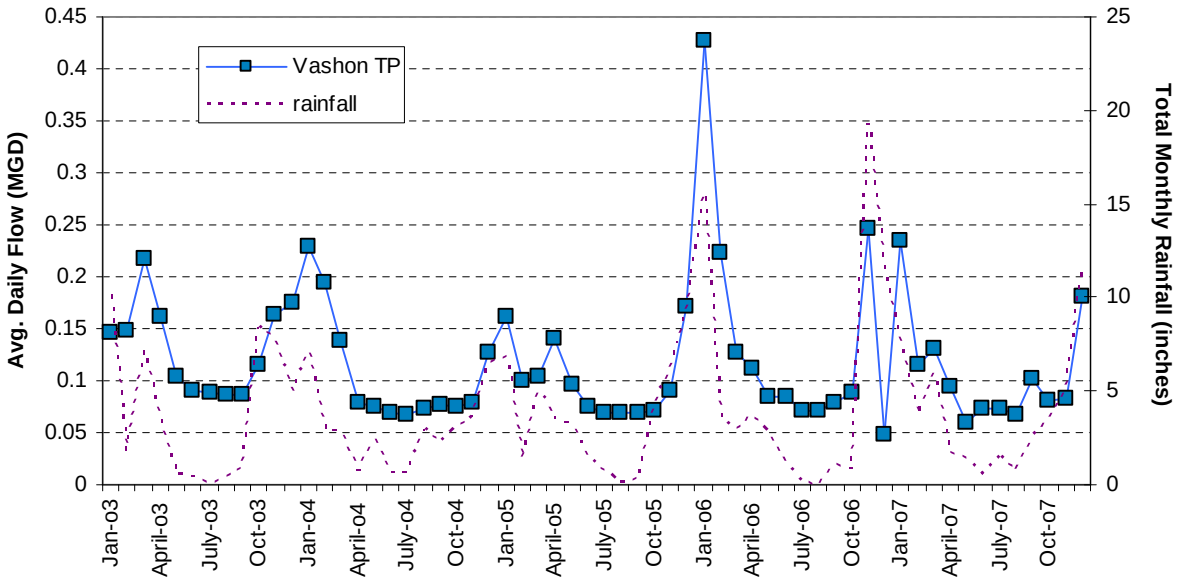

Figure 1-3. Vashon TP Average Daily Flows and Total Monthly Rainfall (measured on northern Vashon Island) Between 2003 and 2007

1.2.1 Permit and Sampling Requirements

The Federal Clean Water Act states that all sewage treatment plants that discharge effluent from a point source into surface waters must have a National Pollutant Discharge Elimination System (NPDES) permit. The permit delineates conditions and quantities that a municipality can discharge to a receiving waterbody. In Washington, the Washington State Department of Ecology (Ecology) administers the NPDES permit program by delegation from the U.S. Environmental Protection Agency (EPA).

King County has four NPDES permits to discharge treated wastewater. The West Point permit (permit # WA-002918-1) includes the West Point TP, Alki and Carkeek CSO TPs, the County's CSOs, and the Elliott West and Henderson/Martin Luther King (MLK) CSO Storage and Treatment Facilities. The Elliott West and Henderson/MLK CSO Facilities were added as an addendum to the West Point permit in 2005. King County also has separate permits for the South TP (permit # WA-002958-1), the Vashon TP (permit # WA-002252-7), and the Carnation TP (permit #WA-003218-2). All treatment plant NPDES permits can be downloaded at the following website http://www.kingcounty.gov/environment/wtd/About/System/NPDES.aspx.

In addition to wastewater treatment NPDES permits, the County also has permits for the production and distribution of reclaimed water, operation of the Beulah Park/Cove Community wastewater system on Vashon Island, and a municipal stormwater permit. More information on

these permits can be accessed at the Wastewater Treatment Division's website at http://www.kingcounty.gov/environment/wtd.aspx.

1.2.2 King County Treatment Plant Descriptions

West Point Wastewater Treatment Plant

The West Point TP service area includes the City of Seattle and areas north and west of Lake Washington. Most of the neighborhoods in the north Lake Washington area were constructed with separate sanitary and storm sewers but within the city of Seattle, approximately 75% was constructed with combined sewers that carry both sanitary sewage and stormwater. Sanitary and combined flows from Seattle are merged prior to arriving at the West Point TP. In addition to domestic sewage, almost all of Seattle's industrial areas discharge to the West Point TP.

The plant is designed to provide secondary treatment of wastewater flows up to 300 MGD. The maximum monthly average design criteria flow is 215 MGD. The secondary treatment process includes screening through bar screens to remove rags and plastics, which are then flushed down a trough to grinder pumps. The ground screenings (grit) are cleaned and dewatered. From 2005 to 2007, the grit was recycled in a composting facility. Liquid wastewater treatment includes primary sedimentation, biological treatment using activated sludge and oxygen, secondary clarification, chlorine disinfection, and dechlorination. The primary treatment process for flows above 300 MGD and up to 440 MGD (the maximum instantaneous capacity) consists of screening, degritting, primary sedimentation, chlorine disinfection, and dechlorination. Treated wastewater (effluent) is discharged to Puget Sound through an eight-foot diameter concrete outfall with a 600-ft long diffuser, located approximately 3,400 ft offshore at a depth of 240 ft MLLW. A detailed description of the West Point TP can be accessed at the following website http://www.kingcounty.gov/environment/wtd/About/System/West.aspx.

South Wastewater Treatment Plant

The South TP service area includes the areas and cities east of Lake Washington and Lake Sammamish and the Muckleshoot Tribe and the cities of Renton, Tukwila, Kent, Black Diamond, and Auburn. The service area includes 32 jurisdictions and utility districts. All flows to the South TP are from separated sanitary systems with the exception of a small portion (approximately 4%) of the Seattle system that is a combined system. The plant's design criteria for maximum monthly average flow is 144 MGD but the plant can handle flows of up to 325 MGD.

The secondary treatment process consists of screening, degritting, primary sedimentation, grease removal, biological treatment using activated sludge and oxygen, secondary clarification, and sodium hypochlorite disinfection. Pumps transport the treated wastewater from the plant to the Puget Sound outfall located almost two miles off a point of land north of Alki. The outfall

includes a 500-ft long diffuser and terminates about 10,000 ft offshore at a depth of approximately 600 ft MLLW. The facility produces Class A water for reuse from a small portion of the plant's flow. The chlorinated effluent is treated using coagulation and filtration. The water then flows through sand filters and is disinfected with hypochlorite. The treated solids are used to create a biosolids product that is used in eastern Washington for agriculture applications and in western Washington for forest applications and commercial composting. A description of the South Plant treatment process is available at the following website http://www.kingcounty.gov/environment/wtd/About/System/South.aspx

Vashon Wastewater Treatment Plant

The Vashon TP serves the Vashon Sewer District and treats wastewater from about 425 residential and commercial customers in and around the Island's main business area, located near the northeastern portion of Vashon Island. Major upgrades to the plant began in 2004 and were completed in 2006. The plant has an instantaneous maximum capacity to treat 1.0 MGD and a design criteria maximum monthly average of 0.5 MGD.

The secondary treatment process first consists of screening out large debris through a bar screen. Secondary treatment is accomplished in an oxidation ditch with clarification occurring in a secondary clarifier. Solids are removed from the secondary clarifier and dewatered in a belt filter press before being transported to the South Plant. Effluent is disinfected using ultraviolet radiation prior to discharge through the Puget Sound outfall. The outfall discharges at a depth of approximately 200 ft MLLW and 2,800 ft offshore. The outfall is an eight-inch pipe with no diffuser. A detailed description of the Vashon Treatment Plant can be accessed at the following website http://www.kingcounty.gov/environment/wtd/About/System/Vashon.aspx.

Alki CSO Treatment Plant

The Alki CSO TP is located in West Seattle near Alki Point and was constructed in 1958 as a primary treatment plant to serve an area of 4,095 acres. The service area is primarily residential with some commercial activity mainly along portions of California Avenue and SW Alaska Street. There are no significant industrial users discharging to the Alki plant. The plant was overhauled in 1987 to enclose the facilities and retrofit the mechanical and electrical systems. In 1998, the plant was remodeled to operate as a near-fully automated CSO treatment plant and was phased out of operation as a sewage treatment plant.

The Alki TP operates intermittently, only when flows in the Alki service area exceed 18.9 MGD and the West Seattle storage tunnel is full. For flows less than 18.9 MGD, the flow is transferred directly to the West Point TP for secondary treatment without entering the Alki plant. Wet weather flows in excess of 18.9 MGD and the 7.1 million gallon storage capacity of the West Seattle tunnel are diverted to the Alki CSO TP for treatment. Treatment consists of screening, and primary sedimentation followed by chlorine disinfection and dechlorination. Treated flows are discharged to Puget Sound via a 42-inch outfall that is about 1,136 ft offshore at a water depth of 143 ft MLLW. Flows in excess of 65 MGD can be discharged via the 63rd Avenue pump station outfall, which is a permitted CSO located south of the Alki TP.

Carkeek CSO Treatment Plant

The Carkeek CSO TP was constructed in 1962 as a primary treatment plant to serve the Carkeek Basin. It is located in north Seattle within Carkeek Park. In 1994, the plant was converted to a pumping station/CSO treatment facility. During dry weather and normal flows, the facility operates as a pump station only; pumping wastewater to the West Point Treatment Plant. The Carkeek TP operates intermittently, only when the combined sanitary/storm water flow during a storm exceeds the pump capacity of the Carkeek Pump Station (9.2 MGD). The excess flow is stored and treated in the plant and then returned to the pump station at the end of the storm. From the pump station, the flow is pumped to the West Point TP. If flows exceed the storage capacity of the treatment plant, the treated flows are then discharged to Puget Sound via a 4,200-ft long outfall at a water depth of approximately 200 ft MLLW. After the storm, any stored flow remaining in the plant is pumped to the West Point TP.

The treatment process at the Carkeek TP consists of screening, degritting, primary sedimentation, disinfection with sodium hypochlorite, and dechlorination. Dechlorination was added to the plant in 2005. In the grit tank, the flow is aerated and grit is pumped to the storage tanks. From the grit tanks, the flow moves into two primary sedimentation tanks. Any settled solids in these tanks are pumped to the storage tanks. When both sedimentation tanks are full, the flow moves to the chlorine tank for disinfection and is dechlorinated before being discharged out the outfall.

Elliott West CSO Facility

The Elliott West CSO Storage and Treatment Facility became operational in May 2005 and was a joint effort between King County and the City of Seattle Public Utilities to control CSO overflows into Lake Union and Elliott Bay. This new facility is the largest CSO control facility in the County's wastewater conveyance system.

The facility has two modes of operation. During rainstorms, the facility will direct combined stormwater and sanitary sewer flows into the Mercer Street wastewater storage tunnel. This scenario is expected to occur about 50 times a year. Following each storm, the CSO control facility will pump the stored flows from the tunnel to the Elliott Bay interceptor, which will then direct the flows to the West Point TP. During larger rainstorms, expected about 10 to 20 times a year, the Mercer Street tunnel will be filled to capacity. When this happens, the facility will begin to treat the stored flows and then pump them to a newly constructed marine outfall in Elliott Bay. The Elliott West outfall is 490-ft in length and discharges at a depth of about -63 ft MLLW. Treatment includes screening out floatable materials, disinfection, and dechlorination.

During very large storms, expected to occur once per year on average, flows may exceed the facility's storage and pumping capacity of 250 MGD. When this occurs, untreated flows will be discharged through the new shorter marine outfall at Myrtle Edwards Park. The outfall is 100-ft in length and discharges at a depth of approximately -20 ft MLLW.

Henderson/Martin Luther King CSO Facility

The Henderson/Martin Luther King (MLK) CSO Storage and Treatment Facility became operational in July 2005. The project was initiated to decrease CSO overflows into Lake Washington and the Duwamish River. Prior to facility construction, CSO overflows from the Rainier Beach area flowed into Lake Washington. The new facilities consists of a 3.2 MG storage tunnel with treatment capabilities and conveyance lines that will store flows during rainstorms and then route the flow to either the South or West Point TPs for treatment. The Henderson Pump Station was also upgraded to add capacity to the system and further reduce the potential for overflow events.

The tunnel was designed to provide wastewater storage during rainfall events. When the storm event subsides, the stored flows will be conveyed primarily to the South TP but can also be conveyed to the West Point TP for secondary treatment. In the event the storage tunnel is filled to capacity during extreme storms and water continues to flow into the tunnel, the flow will be treated and then pumped and discharged through the Norfolk outfall into the Duwamish River. The flows will be disinfected prior to discharge through the Norfolk outfall. The Norfolk outfall is located on the north bank of the Duwamish River at approximately river mile 6.5.

1.3 Other Puget Sound Discharges

There are several types of anthropogenic inputs that enter Puget Sound marine waters. A brief description of the major inputs is provided below. Figure 1-4 shows wastewater treatment plant discharge locations within Puget Sound. CSO and stormwater discharge locations within western King County are shown in Figure 1-5.

1.3.1 Other Wastewater Treatment Plant Discharges

There are municipal wastewater treatment plant discharges into Puget Sound originating from city, county, tribal, federal, and privately operated wastewater treatment facilities. Besides King County's facilities, there are 50 other permitted wastewater facilities with marine discharges to Puget Sound, excluding facilities on the outer coast and north of Admiralty Inlet. Figure 1-4 shows the locations of wastewater treatment plant that have discharges to Puget Sound marine waters. Discharge volumes and discharge distance offshore vary dependent upon the capacity of the facility. Most treatment plant outfalls are located close to shore, with the exception of the Kimberly-Clark marine outfall in Port Gardner, which is located 2,700 ft offshore.

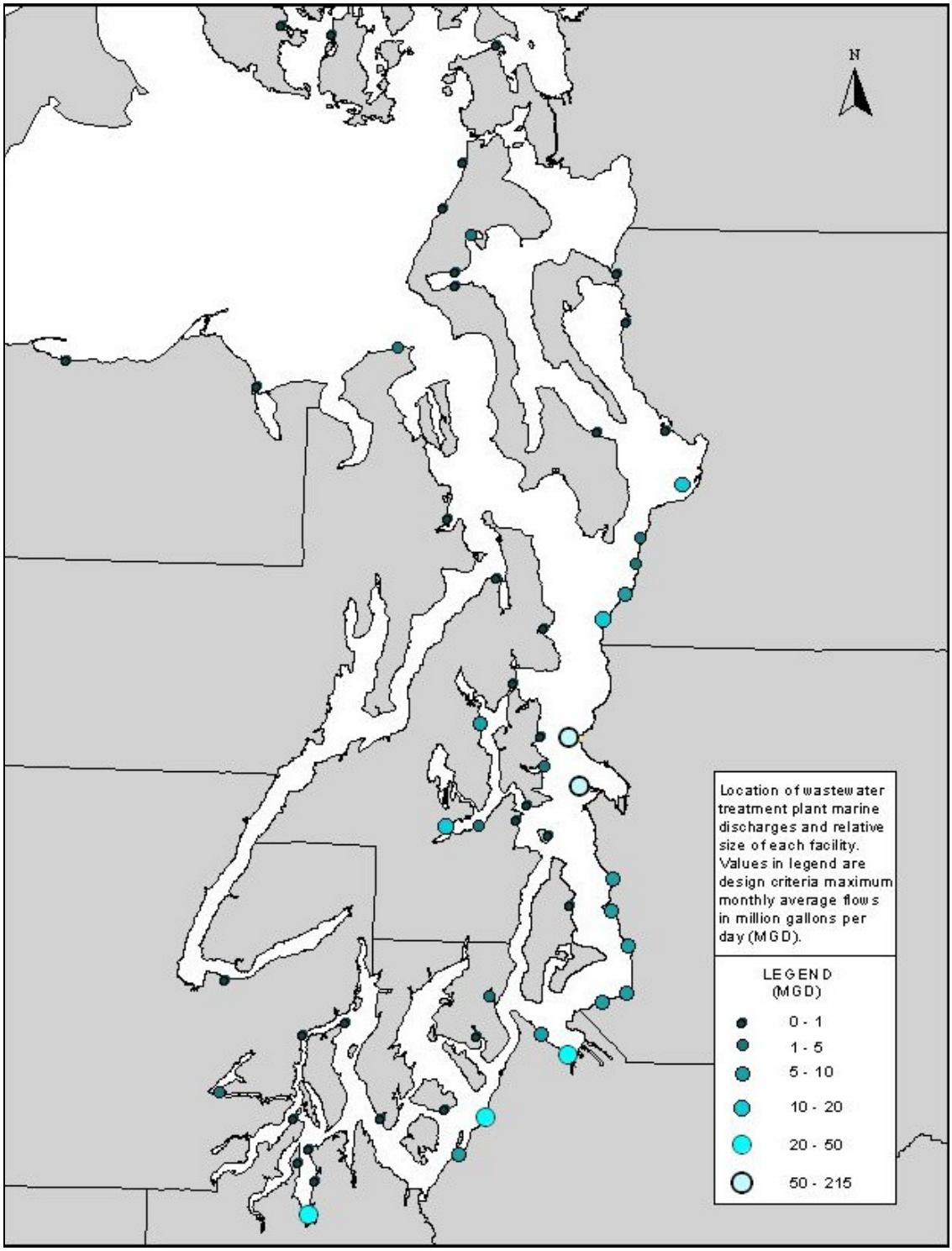

Figure 1-4. Puget Sound Wastewater Treatment Plant Marine Discharge Locations

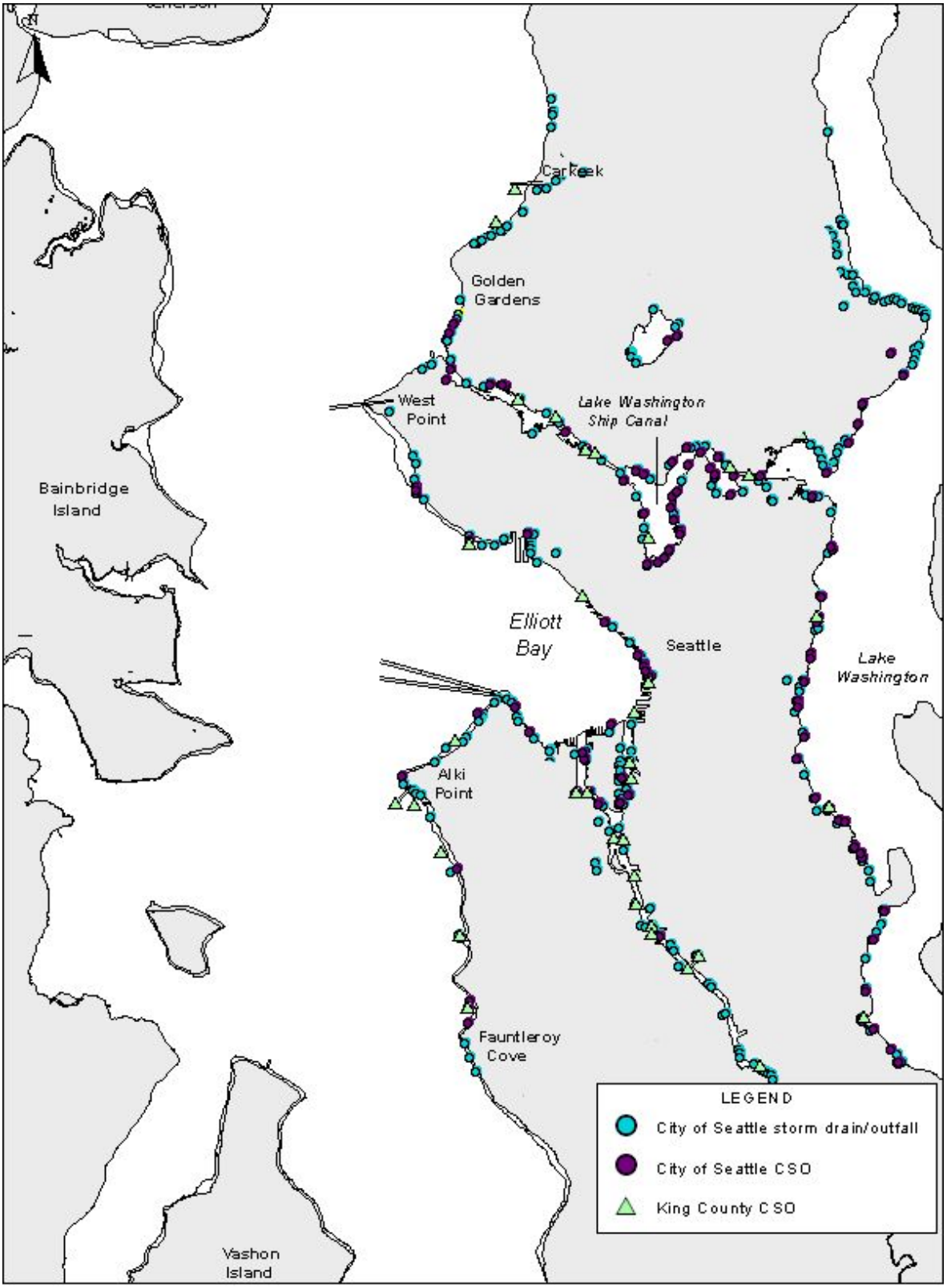

Figure 1-5. Location of CSO and Stormwater Discharges in Western King County

1.3.2 Combined Sewer Overflow Discharges

CSO discharges consist of untreated sewage and stormwater that occur when sewers have reached their capacity during heavy rainfall events. Between the late 1800s and 1940s in the City of Seattle, engineers designed combined sewer systems to convey both sanitary sewage and stormwater runoff in a single pipe to the nearest receiving body of water. In the early 1950s, most sewer systems were built as separated systems which conveyed sewage in one pipe and stormwater runoff in another pipe. In the late 1950s, treatment plants were built to treat wastewater. Combined sewer systems still exist in portions of older cities, including Seattle. Figure 1-5 shows locations of King County and City of Seattle CSOs in western King County. All the CSOs within King County are in Seattle, as this is the oldest part of the sewer system that is not separated. Wastewater and stormwater from other parts of King County are separated, with the wastewater conveyed to treatment plants for treatment before being discharged. There are long-term control plans for reducing the frequency and volume of all CSOs in Washington State to the required limit of no more than one untreated overflow event per year.

1.3.3 Stormwater Discharges

Stormwater runoff is water that flows off surfaces such as paved streets, rooftops, parking lots, and lawns. Stormwater can contain a variety of pollutants, dependent upon the runoff source. For example, runoff from parking lots and streets can contain hydrocarbons from combustible fuel, while runoff from lawns and grassy areas can contain pesticides and herbicides. In urban areas, stormwater is collected through storm drains and can then be conveyed in different ways. Stormwater can be conveyed to treatment systems for various types of treatment before being discharged to a receiving water body or be directly discharged through a stormwater outfall without receiving treatment. Figure 1-5 shows the location of storm drains and CSOs (which contain some portion of stormwater) within the western portion of King County.

In 1987, the Clean Water Act was amended to require certain industries and municipalities to have a NPDES permit for stormwater discharges. The EPA stormwater regulations for Washington State established two phases for the stormwater permitting process. Phase I permits promulgated in 1990 cover stormwater discharges from certain industries, construction sites over five acres, and municipalities with a population over 100,000 people. King, Snohomish, and Pierce Counties, the City of Seattle, and the City of Tacoma are all covered under the Phase I municipal stormwater NPDES permit. The municipal stormwater permit requires the implementation of a Stormwater Management Program, which includes a plan to reduce the discharge of pollutants through discharge of stormwater, reduce impacts to receiving water, and eliminate illegal discharges. The Phase II regulations promulgated in 1999 expanded the requirements for stormwater permits to all municipalities located in urbanized areas and construction sites between one to five acres.

1.4 Sampling Area

King County's sampling area is located within the Puget Sound Central Basin, extending south to Dumas Bay and north to Edwards Point. Elliott Bay, a large urban embayment which includes the City of Seattle waterfront, is also located within the County's monitoring area. All but four sites sampled between 2005 and 2007 as part of the marine monitoring program were located in marine waters. One brackish site was located in the Lake Washington Ship Canal directly west of the Ballard Locks, two sites were located in the lower Duwamish Waterway, and a freshwater site was located in Piper's Creek. All data, with the exception of the two Duwamish Waterway sites, are reported in this document.

1.4.1 Sampling Area Characteristics

Puget Sound is a fjord-like estuary that extends approximately 230 kilometers (km) in a north-south direction and is bordered by the Olympic mountains to the west and the Cascade mountain range to the east. Puget Sound consists of a series of underwater valleys and ridges (called basins) and submerged hills (called sills). Sills impede the flow of water in and out of the Sound and also induce vertical mixing as water moves over the sill. The Sound consists of four major interconnected basins, including the Main (Admiralty Inlet and the Central Basin), Whidbey, Southern, and Hood Canal Basins. The Whidbey Basin is not a basin in the geological sense; its southern boundary is an arbitrarily chosen line running from Possession Point on Whidbey Island across the channel to Picnic Point in southern Snohomish County.

Water from the Pacific Ocean enters the Sound primarily through Admiralty Inlet and secondarily through Deception Pass. The area where Possession Sound and Admiralty Inlet join with the Central Basin is referred to as the Triple Junction. The Main Basin, with depths greater than 280 m, is shielded at the northern entrance to the Sound by the Admiralty Inlet Sill which impedes the exchange of deep waters. However, the Sound has near-oceanic salinity throughout the year and is supplemented with cold, nutrient-rich, low-oxygenated, deep oceanic water upwelled off the Washington coast during the late summer months.

Puget Sound has an average depth of 106 meters (m) and contains approximately 168 billion cubic meters of water. The average tidal range is 3.7 to 4.3 m and an average water volume exchange of 8 billion cubic meters occurs with each tidal cycle (King County, 1994). A mixed semi-diurnal tide, which is characterized by two unequal high tides and two unequal low tides occurring each day, dominates the tidal pattern within Puget Sound. These relatively high water exchange rates are conducive to maintaining overall favorable water quality conditions in Puget Sound.

Many complex factors influence water quality in Puget Sound, including water currents, physical, biological, and chemical processes, and human activities. Offshore water samples consistently indicate good water quality. However, nearshore waters and sediments tend to exhibit more water quality problems due to proximity to pollutants from industrial and urban

sources. Bacteria levels in nearshore waters are consistently higher than in offshore waters due to proximity to sources such as storm drains, freshwater input (creeks and streams), and urban wildlife. Sediment carried in runoff from land plays a much greater role in Puget Sound's water quality than in most marine areas. Being surrounded by hills, lakes, and rivers in an urbanized area with substantial rainfall gives the Sound a multitude of complex sediment sources. The predominant sediment sources are from river transport and bluff erosion. The twelve largest rivers entering Puget Sound contribute approximately 1.8 million cubic meters of sediment annually. Their suspended sediment load is highest during winter and early spring when heavy seasonal precipitation from storms erodes soil from the surrounding lowlands. Sediment sampling generally shows the highest levels of organic chemicals are found in nearshore areas of Elliott Bay, where urban runoff from storm drains, industrial sources, and nonpoint sources is the greatest.

Around September 2006, a mild El Niño event (a warming episode of Pacific Ocean waters) developed in the Pacific Ocean and dissipated in early 2007. This El Niño event was milder than the very strong 1997/1998 event. La Niña conditions (a cooling phase of Pacific Ocean waters) were observed in late summer of 2007 and persisted until early spring of 2008.

1.4.2 Freshwater Input

In an estuarine environment such as Puget Sound, freshwater flows from rivers and streams are important as they affect both physical and biological processes. Freshwater flows influence Puget Sound water circulation as the amount of freshwater input varies seasonally and affects water temperature, salinity, and density, which then determines stratification of the water column. Water column stratification can affect biological populations by trapping nutrients and/or affecting vertical migration through the water column. Freshwater flow also affects the amount of nutrients and contaminants transported into marine waters. Freshwater input into rivers is mainly through rainfall, however, snowmelt also contributes a large source in later spring and early summer.

There are two main freshwater inputs into the Central Basin marine waters: the Green/Duwamish River system, which enters Elliott Bay and the Lake Washington Drainage Basin (Cedar River) which flows into the Sound primarily through the Lake Washington Ship Canal. The Skagit, Stillaguamish, Snohomish, and Puyallup Rivers all have substantial freshwater flows, particularly the Skagit River, and can affect marine waters within the Central Basin (Figure 1-6a). There are also numerous smaller streams that discharge directly into nearshore Puget Sound waters.

Freshwater flows can increase in late spring and summer from snowmelt, but are dependent upon the location and hydrology of the drainage basin. An increase in freshwater flow is evident during late May to early July in the Skagit River (Figure 1-6b) and also in May and June in the Puyallup River. However, due to regulated flows in the Lake Washington Drainage Basin and the Green River, snowmelt does not increase the flows in these river systems to the extent that it does in other systems.

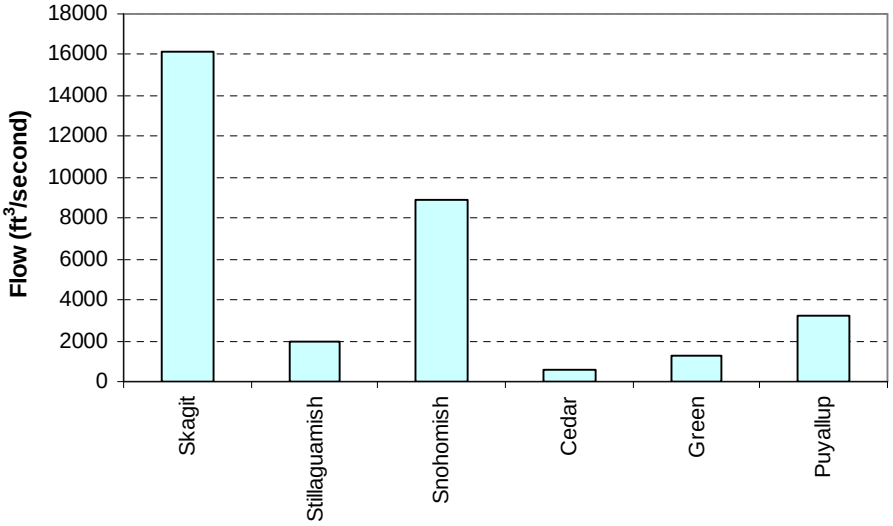

Figure 1-6a. 5-Year Average Annual Streamflow for Six Rivers (2003-2007)

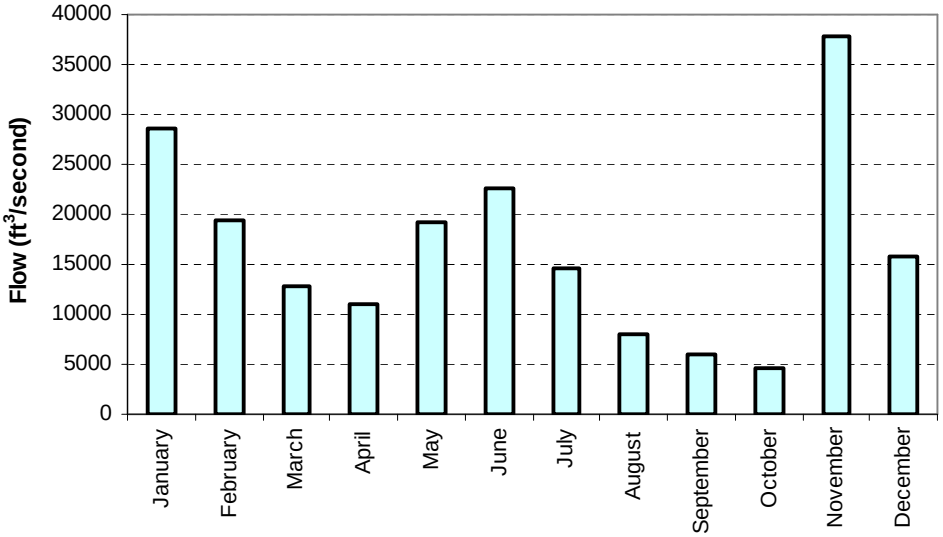

Figure 1-6b. Monthly Mean Streamflow for the Skagit River in 2006

1.4.3 Oceanographic Characteristics

General Circulation Patterns

Water circulation in Puget Sound generally consists of a two-layered flow, with incoming, saltier oceanic water flowing along the bottom and a fresher, less dense water layer flowing out at the surface. The largest single source of freshwater into Puget Sound is the Skagit River, followed by the Snohomish and Stillaguamish Rivers, all of which flow into the Whidbey Basin. The

Puyallup and Nisqually Rivers are the largest freshwater sources into southern Puget Sound. The largest sources of freshwater input into the Central Basin are the Duwamish River, which flows into Elliott Bay, and water from the Lake Washington Ship Canal. The freshwater flow is driven by freshwater runoff from rainfall and the summer snow melt. Salty, cold dense waters enter Puget Sound at depth through Admiralty Inlet and a portion flows south in the Central Basin while the other portion flows northeast through Possession Sound to the Whidbey Basin. Figure 1-7 shows the net circulation pattern in Puget Sound with the deep incoming water flowing beneath the outflowing upper layer. Water tends to flow faster on the eastern side of the Central Basin near Alki Point and Point Wells and along the western side near Point Monroe and north of Kingston, where major topographic features affect the currents. The deeper, denser waters in the Main Basin often move 5 to 10 times faster than deeper currents in the Whidbey Basin as a result of vigorous mixing at the Narrows (Ebbesmeyer and Cannon, 2001).

The circulation of inflowing and outflowing water is affected by the sills, which provide vertical mixing of the two water layers. An exception to the two-layered flow in the Main Basin occurs in the southern portion around Vashon Island. In this area, the net flow is mainly southward through East Passage, around the southern end of Vashon Island, and then north through Colvos Passage (see Figure 1-7). This effect is caused by the location of Vashon Island relative to the outflowing water from the Narrows. The outflow from Colvos Passage has a significant effect on surface circulation in the northern portion of the Central Basin (Ebbesmeyer and Cannon, 2001). Water moving northward through Colvos passage is directed across the channel towards Alki Point, where a portion then returns south in East Passage. The other portion flows north toward the Triple Junction, the area where waters from the Central Basin, Whidbey Basin, and Admiralty Inlet converge.

Winds can cause significant variations in circulation. Southerly winds augment the surface outflowing water and northerly winds can impede and sometimes reverse the surface flow. Bottom water intrusions can also cause significant variations in circulation. Intrusions occur when dense saltwater crosses the Admiralty Inlet sill and replaces deep water in the Main Basin. Bottom water intrusions circulate down Puget Sound at speeds of about 20 centimeters per second (cm/s) near the Admiralty Inlet sill and 10 cm/s along the Central Basin (Ebbesmeyer and Cannon, 2001).

The residence time of water in the Main Basin is about 48 days, depending upon the time of year (Babson, 2004).

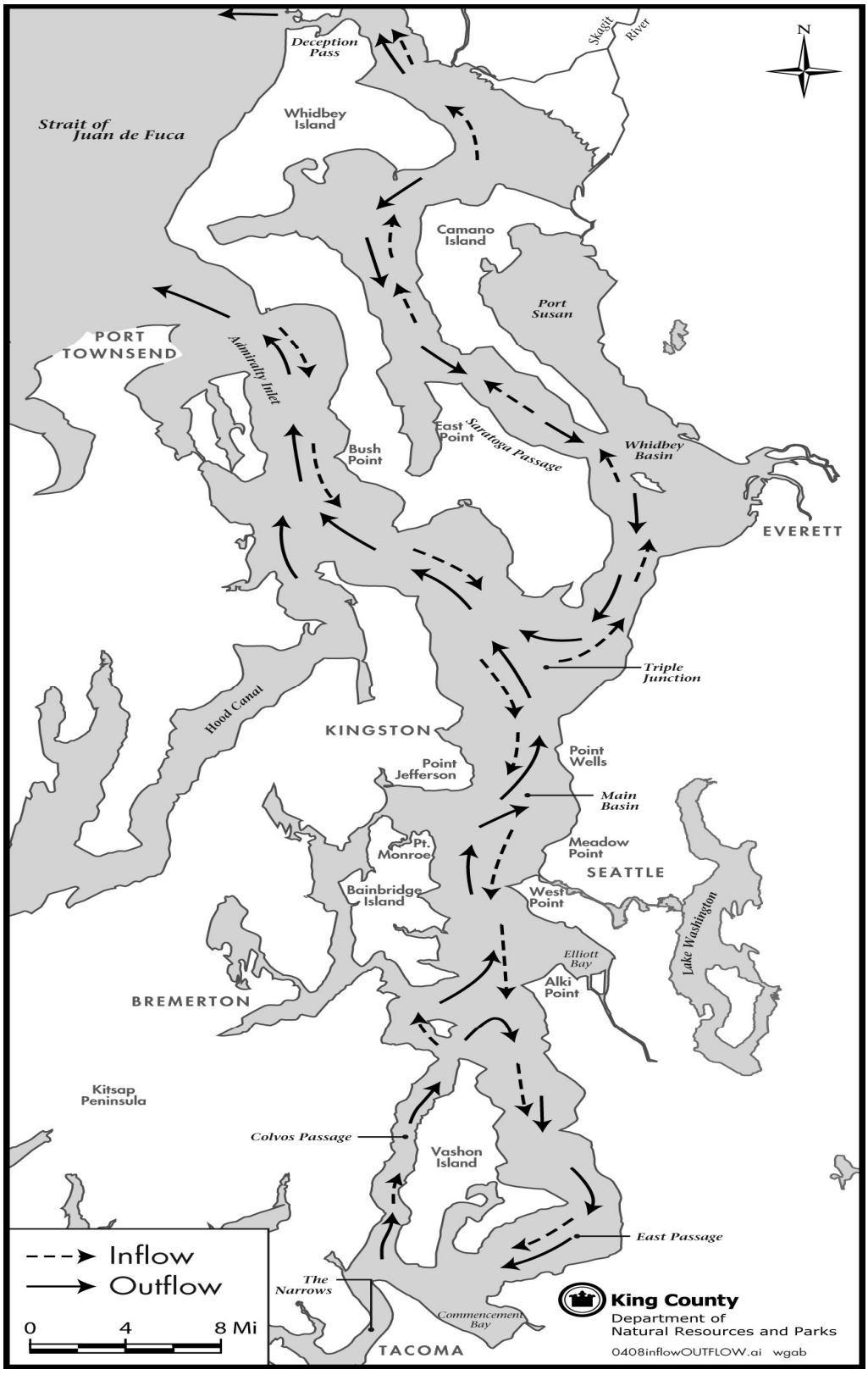

Figure 1-7. Generalized Puget Sound Circulation (from Ebbesmeyer et. al, 2002)

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